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An analysis of the use of Linear Scheduling Techniques in the construction industry.

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An Analysis of the use of Linear Scheduling Techniques in the Construction Industry

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A REPORT PRESENTED TO THE GRADUATE COMMITTEE
OF THE DEPARTMENT OF CIVIL ENGINEERING IN
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ABSTRACT: A construction scheduling technique is presented which is, in many cases, more advantageous, to both the contractor & the owner, than bar charts typically provided by contractors, particularly for projects that are linear in nature or have repetitive activities scheduled in phases (e.g. roads, piping systems, bridge spans, and high rise buildings). The technique is labeled *the linear scheduling method* because it is most useful in the construction industry for projects that are linear in nature. The technique maps planned or actual work along the length, or stations, of a project versus time. The basic application of this method is described. Examples of practical application are provided, including a comparative analysis based on an actual Florida Department of Transportation construction project. The technique is compared to the more prevalent bar chart technique utilized in such software applications as *Primavera Project Planner*.

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Chapter 1
Introduction

1.1 General Comments

Based on a review of published literature, this report presents a basic methodology and case study for linear scheduling (also known as the Linear Scheduling Method or LSM) and suggests the advantages of LSM over other scheduling techniques (eg. Critical Path Method - CPM) as a planning tool for linear operations in the construction industry.

The research for this report focuses primarily on road construction; however, the data, conclusions and recommendations expressed herein may likewise be applied to all types of linear construction operations.

1.2. Scope

The scope of this report relates to basic linear scheduling techniques and the advantages of LSM over CPM for linear operations. The report is not intended to serve as a complete guide to every potential application of linear scheduling or all its complexities.

1.3 Background

It is well understood in the construction industry that all projects require some degree of planning and scheduling; as the complexity of the project increases, so does the need for a systematic methodology. Currently, the construction industry predominately utilizes some form of network analysis to determine the "critical path" and generate a bar chart schedule (i.e. CPM techniques). This is often done with the aid of commercial software such as the Primavera Project Planner® or Microsoft Project®.

The Naval Facilities Engineering Command, Florida Department of Transportation (FDOT), and most, if not all, other government agencies, require in their project specifications that contractors

develop and submit a project schedule for review and approval. Some public agencies use standard specifications so stringent that, regardless of the circumstances of a particular project, the successful bidder is forced to use a particular scheduling technique, or even specific scheduling software. FDOT specifies, for example:

"... Within 30 calendar days after the contract has been executed or at the preconstruction conference, whichever is earliest, the successful bidder shall submit to the Engineer a *Critical Path Method (CPM) schedule* for the project ..." (emphasis added).

The entire FDOT progress schedule specification consists of several pages of specific requirements; the standard construction specifications used in the federal prison system contain more than 20 pages on progress schedule requirements alone. Such specifications are generally so specific that not only a certain method (e.g. CPM) is required, but a certain, proprietary software is often required. These types of specifications, while ensuring thorough project planning, often are overly specific. As in the case of a linear type of project, such specification may tend to require a scheduling technique that is not well suited to the construction operations that will be performed.

Although the requirement for scheduling is accepted by members of the construction industry, more emphasis should be placed on developing *and following* an executable progress schedule rather than simply complying with a contractual obligation to prepare *and submit* a schedule. The level of detail in a progress schedule *and the specific type of schedule to be used* should therefore be commensurate with the needs of the project.[1]

Many types of construction projects involve operations that are repetitive in nature. Examples include the construction of roadways, pipelines, sewer and drainage systems, residential developments, and high-rise structures. In such instances, it may be worthwhile to utilize linear scheduling techniques rather than the CPM techniques that predominate the industry today.

In short, CPM-type schedules require the following for linear operations:

- an artificial break in adjacent, continuous activities to allow for the constraints one activity may place on a subsequent or follow-on activity; and/or

- numerous and cumbersome start-to-start, start-to-finish, and finish-to-finish activity relationships that increase the opportunity for error or omission in developing, following and updating project schedules.

This is demonstrated in the following, simplified example; the value of LSM relative to CPM becomes more clearly evident after a review of Chapter 5 of this report, which compares an actual FDOT highway project schedule to an LSM schedules produced by the author for the same project.

1.3.1 Comparative Analysis via a Simplified Example

As seen from tables 1-1 and 1-2, the progress logic for a linear project is greatly simplified when linear scheduling techniques are used. Likewise, Figures 1-1 and 1-2 demonstrate the reduction in graphic complexity when using the LSM technique vice the CPM.

Project Description: Construct a length of roadway to facilitate growth in an existing family housing area. The road is to be paved with bituminous cement over a crushed stone base course, having cast-in-place concrete curbs & gutters with driveway access on both sides; an existing storm sewer inlet will allow storm water to drain into an existing system.

[Continued on next page.]

Basic Operations (LOB) Table 1-1

Op No.	Description	Production Rate	Constraints	
01	Excavate subgrade	X per day		
02	Compact subgrade	X per day		
03	Place Base Course	½X per day		
04	Place Curb & Gutter	½X per day		
05	Place Prime Coat	3X per day		
06	Place Surface Course	X per day		
07	Paint Centerline	3X per day		

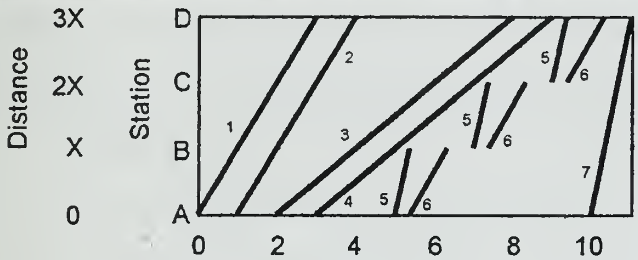

Figure 1-1

Note that this schedule allows the manager to relate time and distance. This allows the manager to estimate progress within an activity (e.g. Op 03 should be at station X+YY at the end of the n[th] day).

Basic Activities (CPM) Table 1-2

Act No.	Description	Duration	Predecessor	
100	Section A-B	--		
101	Excavate Subgrade	1		
102	Compact Subgrade	1	101	
103	Place Base Course	2	102	
104	... etc.		103 (ss=1)	
200	Section B-C			
201	Excavate Subgrade		101	
202	... etc.		102, 201	
300	Section C-D			
...	etc.			

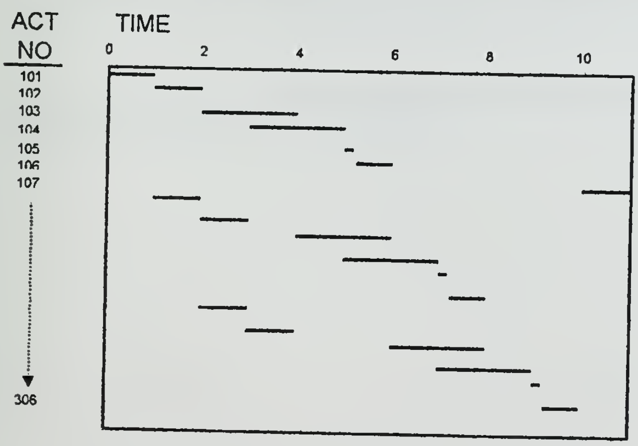

Figure 1-2

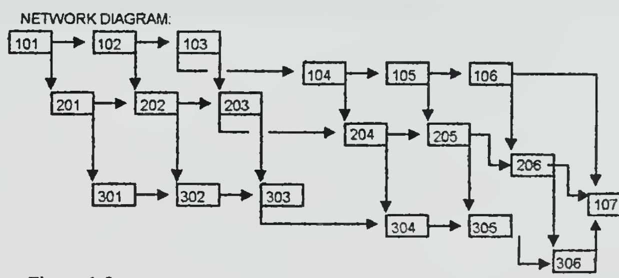

Figure 1-3

1.4. Application for the US Navy

U.S. Navy construction contracts administered by the Naval Facilities Engineering Command require contractors to submit a progress schedule for review and approval. As with other sectors of the construction industry, Navy contractors predominately utilize CPM techniques and bar charts. Likewise, construction projects executed by the Naval Construction Force (e.g. Naval mobile Construction Battalion projects) are required to be planned and scheduled using specific CPM-based software. As stated above, this proves to be unnecessarily cumbersome for projects involving linear operations. For the Navy, these projects may include, but are not limited to:

- Paving;
- Storm Water Drainage Construction;
- Sanitary Sewer Construction;
- Fresh Water & Fire Hydrant Systems Construction;
- Family Housing Construction & Renovation;
- Barracks Construction & Renovation; or
- Multi-Building Facilities Painting Projects.

(It is noteworthy that the Department of the Navy delineated a method for using linear scheduling techniques for industrial processes in its 1962 report, Line of Balance: A Graphic Method of Industrial Programming[2].)

Chapter Endnotes

1. Tarum Bafna. Extending the Range of Linear Scheduling on Highway Construction, Virginia Polytechnic Institute & State University, Blacksburg, VA, August 1991.

2. Line of Balance: A Graphic Method of Industrial Programming, Office of Naval Material, Department of the Navy, April 1962.

Chapter 2
Review of Published Literature

It is not clear form a review of available literature exactly when linear scheduling techniques were first used to develop production schedules. There appears to be a wide variety of names and approaches to scheduling linear projects, with multiple or parallel origins; however, these variations are based on common features: repetitive units of work and known or estimated rates at which these units will be produced[1].

Beginning in the 1950's, the U.S. Navy is known to have used a techniques called *Line of Balance* to plan and monitor the progress of industrial processes[2]. The objective of this method was to determine or evaluate the flow rate of finished products in a production line[3]. The Line of Balance output comprised of two components: a unit network a progress diagram.

The unit network showed the assembly operations for a single unit of many to be produced[4]. This was similar to the linear schedule described in this report in that it typically used time for the horizontal axis and some measure of production on the vertical axis. (The method in this report uses distance for the vertical scale.) The object of the Line of Balance unit network is used to schedule or record the cumulative events in the completion of a single unit[5]. This approach might be used in planning the construction of a multi-story building; for example, the single unit may be a hotel room or an entire floor. This single unit schedule contrasts with the approach described in this report. The linear schedule, as described in this report, is used to plan or record the progress on multiple activities or operations that move continuously in sequence along the length of the project (as in road or pipeline construction).

The progress diagram in the Line of Balance technique is prepared as a bar chart. The bar represents the units produced on a particular day, which is compared to the Line of Balance to determine of the process is on, behind or ahead of schedule[6].

Carr and Meyer concluded in 1974 that the Line of Balance method could be useful in the

construction of repetitive building units[7]. In their 1986 review, Arditi and Abulak identified several failings of Line of Balance when applied to construction. In particular, they point out that extreme care must be taken in the estimation of production rates as the method is sensitive to errors in the activity duration estimates. They also recommend careful selection of the drawing scale and using multiple colors to improve legibility of the schedule[8].

In 1990, Sarraj developed and presented algorithms that resulted in a mathematical Line of Balance model. According to Sarraj, using this method in its mathematical form enabled the development of production and delivery schedules without drawing a diagram; the graphical representation was merely used for illustrative purposes in the process of project control[9-10].

Line of Balance emphasizes the progress diagram. Other linear scheduling techniques emphasize a variant of the Line of Balance unit network; as stated above, this schedule is used to plan or record the progress on multiple activities or operations that move continuously in sequence along the length of the project.

Since the 1970's, a number of linear techniques other than Line of Balance have been developed and explored academically for application in the construction industry. Johnson describes in his 1981 report a method known as the Construction Planning Technique. This technique is used to determine a schedule from what the planner determines to be critical (eg. economic considerations or resource limits) rather than determining the critical path from individual activity durations. The input of this technique is based on production data[11]. Other than comment by Johnson in 1981, this method has received little more than inclusion in historical chronologies since the mid-1970's.

The "Vertical Production Method" was proposed in 1975 by O'Brein for scheduling repetitive units, such as floors in a multi-story building. The schedule is controlled by how long it takes major trades (crews) to move through the building, bottom to top[12]. This model appears to simply be a specialization of the more general linear schedule model, which may be used for horizontal work as well.

Other variants were proposed in the early 1980's. Like the Construction Planning Technique of the 1970's, these variants sought to optimize resources and/or minimize time, determining durations as the schedule is developed rather than before. These methods generally follow the "flow" of work crews rather than (or as well as) following the chronology of activities.

Johnson described a method he felt especially suitable for highway construction in 1981. This schedule included graphical representations other than diagonal lines; he also allowed for varying production rates.[13] Whether developed parallel to or as a result of Johnson's 1981 description, most subsequent study of linear scheduling techniques that is of any practical use follows the same general theme. Subsequent work was reported by Stradal and Cacha (1982), Chrzanowski and Johnson (1988), Russell and Caselton (1988), Sarraj (1990), Bafna (1991), Moselhi and El_Rayes (1992), Vorster, Beliveau and Bafna, (1992), and Russell and Wong (1993). Some of this work *did* include the application of time-cost analyses to the schedule (as is currently done with CPM-based software models by Primavera, Microsoft and others).

In recent years, the most significant work appears to have been by researchers at the University of Iowa[14-15] and at Virginia Tech[16-17-18-19]. This method has also been an area of significant interest at the University of Florida[20-21-22-23-24] in recent years. This recent work is the basis for scheduling method presented in this report.

These techniques appear to have received little interest outside the realm of academia; this is in spite of efforts by the academicians to foster commercial acceptance of the linear scheduling methods since the late 1980's.[25] This is discussed in more detail in Chapters 6 and 7; however, it is generally due to a failure on the part of government agencies (as owners) to recognize the benefits of linear scheduling and adopt its use, and due to a failure on the part of software companies to develop commercially viable linear scheduling products.

Chapter Endnotes

1. J. E. Rowings & D. J. Harmelink, "Micro-Computer Based Linear Scheduling Application for Highway Construction Project Control," Iowa Department of Transportation & Iowa Highway Research Board, October 1995

2. "Line of Balance Technology: A Graphic Method of Industrial Programming," Office of Naval Material, Department of the Navy, April 1962

3. Z. M. Sarraj, "Formal Development of Line-of-Balance Technique," Journal of Construction Engineering and Management, ASCE, 1993

4. D. W. Johnson, "Linear Scheduling Method for Highway Construction," Journal of the Construction Division, ASCE, 1981

5. J. E. Rowings & D. J. Harmelink, "Micro-Computer Based Linear Scheduling Application for Highway Construction Project Control," Iowa Department of Transportation & Iowa Highway Research Board, October 1995

6. "Line of Balance Technology: A Graphic Method of Industrial Programming," Office of Naval Material, Department of the Navy, April 1962

7. R. I. Carr & W. L. Meyer, "Planning Construction of Repetitive Building Units," Journal of the Construction Division, ASCE, 1974

8. D. Arditi & M. Z. Abulak, "Line of Balance Scheduling in Pavement Construction," Journal of Construction Engineering and Management, ASCE, 1986

9. Z. M. Sarraj, "Formal Development of Line-of-Balance Technique," Journal of Construction Engineering and Management, ASCE, 1993

10. J. E. Rowings & D. J. Harmelink, "Micro-Computer Based Linear Scheduling Application for Highway Construction Project Control," Iowa Department of Transportation & Iowa Highway Research Board, October 1995

11. ibid.

12. J. J. O'Brein, "VPM Scheduling for High Rise Buildings," Journal of the Construction Division, ASCE, 1975

13. D. W. Johnson, "Linear Scheduling Method for Highway Construction," Journal of the Construction Division, ASCE, 1981

14. J.E. Rowings, D.J. Harmelink & F. Rahbar, "A Multi-Project Scheduling Procedure for Transportaion Projects," Iowa Department of Transportation & Iowa Highway Research Board, April 1993

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17. Tarum Bafna, "Extending the Range of Linear Scheduling on Highway Construction," Blacksburg, VA, August 1991

18. M. C. Vorster, Y. J. Beliveau & T. Bafna, "Linear Scheduling and Visualization," Transportation Research Record 1351, 1992

19. M. C. Vorster & T. Bafna, Discussion of "Formal Development of Line-of-Balance Technique" by Sarraj (1990), Journal of Construction Engineering and Management, ASCE, 1992

20. Michael Berns, "Developing a Computerized Line of Balance Scheduling Program for Use on Navy and general Industry Construction Projects," University of Florida, 1995

21. Zohar Herbsman, "A technique for Scheduling Linear projects in Civil Engineering," University of Florida (not dated)

22. Zohar Herbsman, "Linear Scheduling," University of Florida (not dated)

23. Donald G. Mueller, Jr., "Linear Scheduling Method," University of Florida, 1997

24. George Nicolopoulos, "The Use of Linear Scheduling in the Management of FDOT Operations," University of Florida, 1997

25. Cordell Pavin, "Software Aids Linear Scheduling," Roads & Bridges, September 1997

Chapter 3
Principles & Processes

3.1 Basic Principles of Linear Scheduling

In general, progress schedules routinely used in the construction industry relate the start and finish dates of construction operations (e.g. bar chart) and possibly the requisite predecessor and successor operations (e.g. CPM network diagram); however, these schedules do not relate the specific progress (planned or actual) of the crew(s) for a given operation. The premise behind the use of linear scheduling techniques is that, for a linearly oriented construction project, it is not only desirable, but advantageous to provide this additional information.

Whereas a bar chart schedule uses "time" and "activities" for axes, a linear schedule places construction operations in a graphical chart bounded by axes of "time" and "space." Using lines to represent linear operations (e.g. milling or paving), bars to represent intermediate, non-linear activities (e.g. bridge pier construction), and boxes to represent either periods of planned inactivity (e.g. winter/cold season) or activities that span space over time, but not necessarily linearly (e.g. clearing & grubbing a large area over a period of days or weeks).

In addition to allowing on-site personnel, as well as managers, to readily determine the necessary start and finish dates of operations and the relative sequence of operations, graphical linear scheduling techniques allow project personnel to anticipate the specific location of a crew at a particular time. As well as being an aid to planning, this feature enables managers to more readily identify delays so that adverse impacts resulting from schedule variances may more readily be minimized.

As discussed in Chapter 2 of this report, there are several variations of the linear scheduling technique. This chapter will provide a specific process for developing a schedule using the technique referred to as the Linear Scheduling Model (LSM); this appears to be the most common and accepted method of linear scheduling in academia today.

3.2 Developing the Schedule

Step 1: Prior physically preparing the schedule, it is of course necessary to determine the parameters and data to be incorporated into the schedule.

First, the scheduler must determine what operations should be included in the schedule. For clarity's sake, extraneous data (that is, data that does not help the on-site manager plan, control and execute the work) need not be included (at worst, the inclusion of such data should be minimized). Having made a list of operations to include, the scheduler should determine how these operations will be represented on the graphic representation (e.g. a line, bar or block - this is discussed in greater detail below). Having prepared a list of operations to include, the scheduler must determine the relative sequence of these operations and any constraints on the relationships between the various operations. Finally, the scheduler needs to determine production rates and for these operations. With this data in hand, the scheduler is ready to put the schedule down on paper.

Step 2: Plotting the schedule begins with development of the "playing field"[1]. One axis is used to measure distance, usually by stations. This axis may also be used to present a profile or plan view of the project. For a highway project, the profile would identify such vertical features as cut and fill or culverts; the plan view would indicate such horizontal features as driveways, bridges or signs. The other axis measures time, which may be appropriately represented in months, weeks, days, or even hours, depending upon the size and complexity of the project. (For example, it may be advantageous for a given project to present the overall schedule in terms of weeks while providing a separate graphical representation of a complex operation as sub-operations in terms of days.) Other enhancements may be added to the "playing field" for ease of use, such as horizontal and vertical sight lines.

Many researchers advocate measuring distance on the horizontal axis and time on the vertical axis.[2] The basis of this preference is that they presume it to be of importance to show a plan view of the project, which presumably is more easily viewed on the horizontal axis. The author disagrees with this view for most applications. Since managers are already familiar with schedules that place time on the horizontal axis, continuing this practice when preparing the linear schedule provides a graphic

representation that more closely fits the users' expectations. Additionally, it is important to note that schedules used on-site are usually rather large (that is paper size is generally much larger than 8½"x11") with the time being the longer axis. This being the case, it is simply easier to view the schedule with time on the horizontal scale.

Step 3: Once the playing field is established, the planning process is transferred to the playing field by using the three primary symbols: bars, lines and blocks.

Step 3a: Because blocks include periods of inactivity, it may be convenient to plot these first. This will prevent the scheduler from inadvertently scheduling work during a planned or required period of inactivity. (For example, the owner may place restrictions on when work may be performed as a matter of convenience - say, when the owner's reps are on holiday, or due to a technical requirement - say, due to temperature requirements for certain types or work.)

Step 3b: Once blocks are in plotted, bars (a line (vertical if time is the horizontal axis, horizontal if time is on the vertical axis) representing a crew working in one place[3]) and lines (representing a crew moving through time and space) may simply be plotted in order of occurrence, based on production rates/durations and any required constraints.

3.3 Simplified, Illustrative Example

Consider the following simple example: A sub-contractor is tasked with extending an existing sanitary waste pipeline 20 meters in conjunction with construction of a new house in an existing residential development; the last meter of pipe will be under the basement slab with a stub-up.

Step 1: Develop input data. This project, in simple terms, requires the contractor to complete the following activities or operations:

Op #	Description	Style	Remarks/Constraints
1	Move-in/Start-up	Block	Includes staking site limits.
2	Remove/Preserve Sod	Line	Store adjacent to trench.
3	Excavate Trench	Line	Complete sod removal first.
4	Lay Pipe	Line	5-m between Op 3 & Op 4; incl sand bedding.
5	Cap End	Bar	After Op 4; incl 90° elbow & exposed stub-up.
6	Connect to Existing	Bar	After Op 5; incl backfill/compact at connection point.
7	Backfill & Compact	Line	5-m btwn Ops 4/7; must complete all excavation first.
8	Place Sod	Line	Maintain 5-m between Op 7 & Op 8.
9	Clean-up/Move-out	Block	Start when all other work complete.

Table 3-1

Next, the scheduler estimates production rates/durations for the above operations/activities:

Op #	Description	Style	Prod Rate	Remarks/Constraints
1	Move-in/Start-up	Block	1 hr	Includes staking site limits.
2	Remove/Preserve Sod	Line	20 m/hr	Store adjacent to trench.
3	Excavate Trench	Line	10 m/hr	Complete sod removal first.
4	Lay Pipe	Line	50 m/hr	5-m between Op 3 & Op 4; incl sand bedding.
5	Cap End	Bar	15 min	After Op 4; incl 90° elbow & exposed stub-up.
6	Connect to Existing	Bar	45 min	After Op 5; incl backfill/compact at connection point.
7	Backfill & Compact	Line	5 m/hr	5-m btwn Ops 4/7; must complete all excavation first.
8	Place Sod	Line	100 m/hr	Maintain 5-m between Op 7 & Op 8.
9	Clean-up/Move-out	Block	2 hr	Start when all other work complete.

Table 3-2

20-Meter Sanitary Sewer Extension

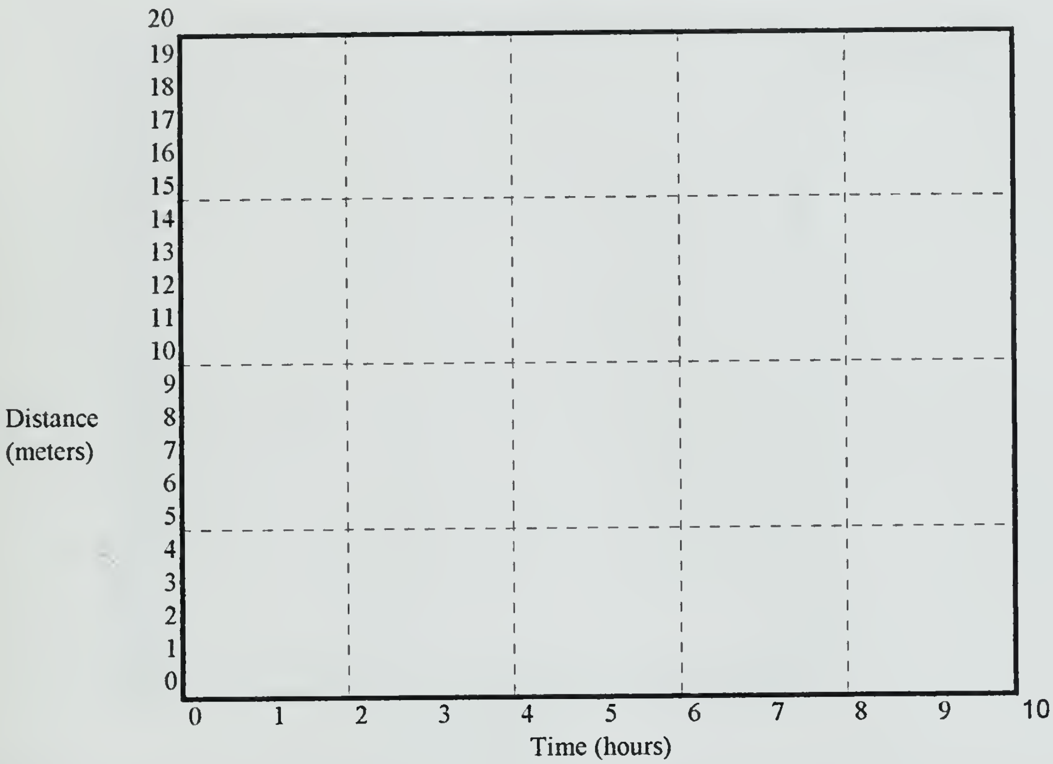


Fig. 3-1

Step 2: Based on the data in Table 3-2, the scheduler may decide to establish the following "playing field" for the graphic linear schedule: (1) use time, in hours, for the horizontal scale; (2) use distance, in meters, for the vertical scale; (3) include sight lines, every 2 hours and every 5 meters. (Refer to figure 3-1, above.)

Step 3: There are no periods of inactivity to be blocked out; plot operations/activities in order of execution:

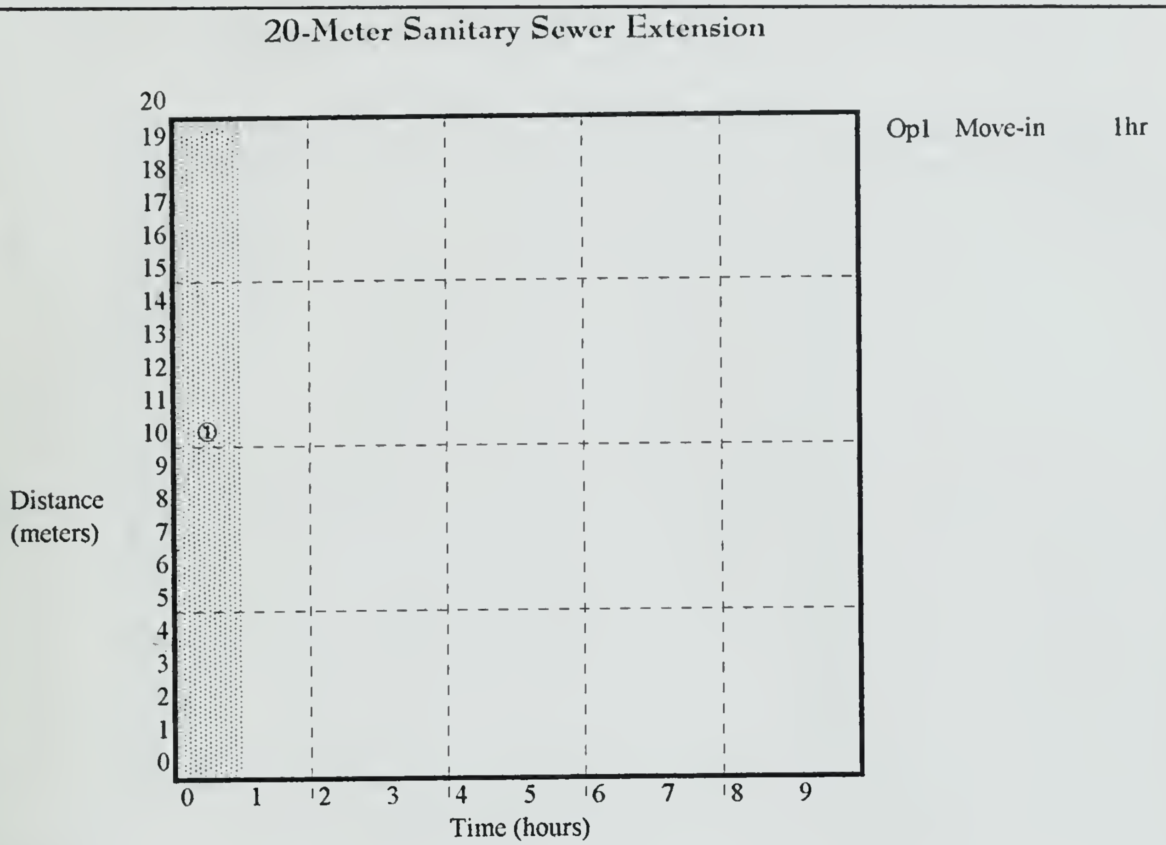


Fig. 3-2

Op 1 - Move-in/Start-up: As the first activity, it will start at t=0.

Construct a block bounded by t=0, t=1, d=0 & d=20. (Refer to figure 3-2, above.)

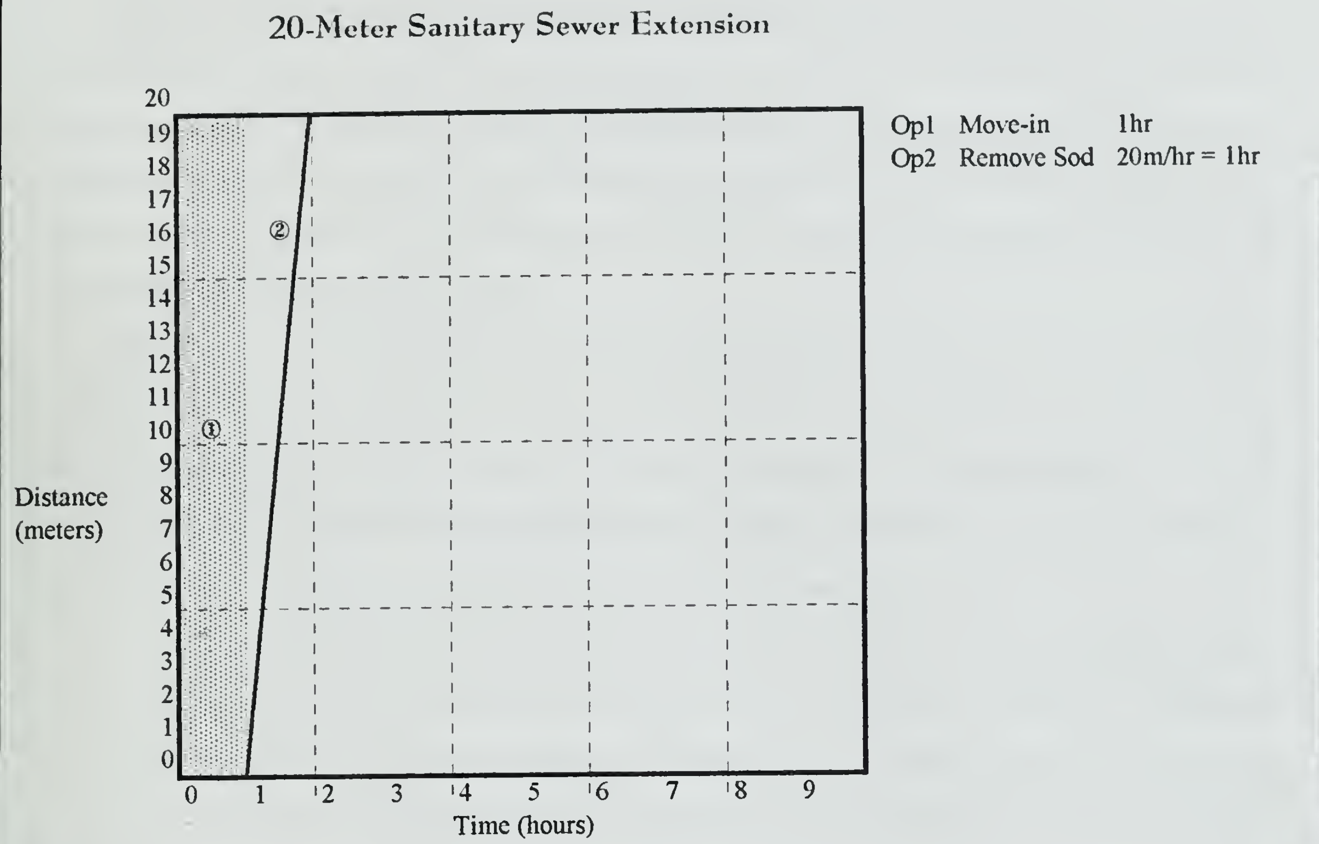


Fig 3-3

Op 2 - Remove/Preserve Sod: The only constraint on this operation is that it will not commence until Move-in is completed. (Note: this may not always be the case. The planner/scheduler should establish reasonable constraints based on the method of construction and resources available, as well as less subjective factors such as contractual requirements.) Based on the assumed constraint, the planned start time of this operation will coincide with the planned finish time of the previous block activity, Op 1.

Construct a line starting at t=1, d=0 and finishing at t=2, d=20. (Refer to fig 3-3, above.)

Op 3 - Excavate Trench: This operation is constrained by the requirement that at any given time, there be a space of at least 10 meters between Op 3 and Op 2. (In this case, this may be a safety requirement to allow a reasonable space between the laborers/equipment removing existing sod and the laborers/crew excavating the trench; absent any contractual or government imposed restriction, this would be at the discretion of project management personnel.) The question now becomes, "How does one construct the line for Op 3 to ensure that this constraint is met?"

First, one must determine the relationship between the slopes of Op 3 and Op 2. If Op 3 has a steeper slop, then the distance between the operations will decrease with time; conversely, if Op 3 has a more shallow slope, then the distance between the operations will increase with time. Here, the latter is true. This means that the critical point with respect to the stated constraint occurs at the start of Op 3. To ensure the constraint is met, use the following procedure:

a. Drop a vertical line (vertical because the constraint is distance-related and distance is the vertical axis) from the earliest point in time on Op 2 at which Op 3 may start. In this case, the constraint is a 10-meter separation; therefore, drop a vertical line from Op 2 at d=10.

b. Op 3 will commence at the point in time where this vertical line intercepts the horizontal axis.

c. The vertical line was simply a tool for constructing the line representing Op 3; therefore, once the line representing Op 3 is constructed, this vertical line may be erased. (Actually, the vertical line may simply be visualized; it need not actually be drawn.)

Construct a line starting at t=1.5, d=0 and finishing at t=3, d=20. (Refer to fig 3-4, next page.)

20-Meter Sanitary Sewer Extension

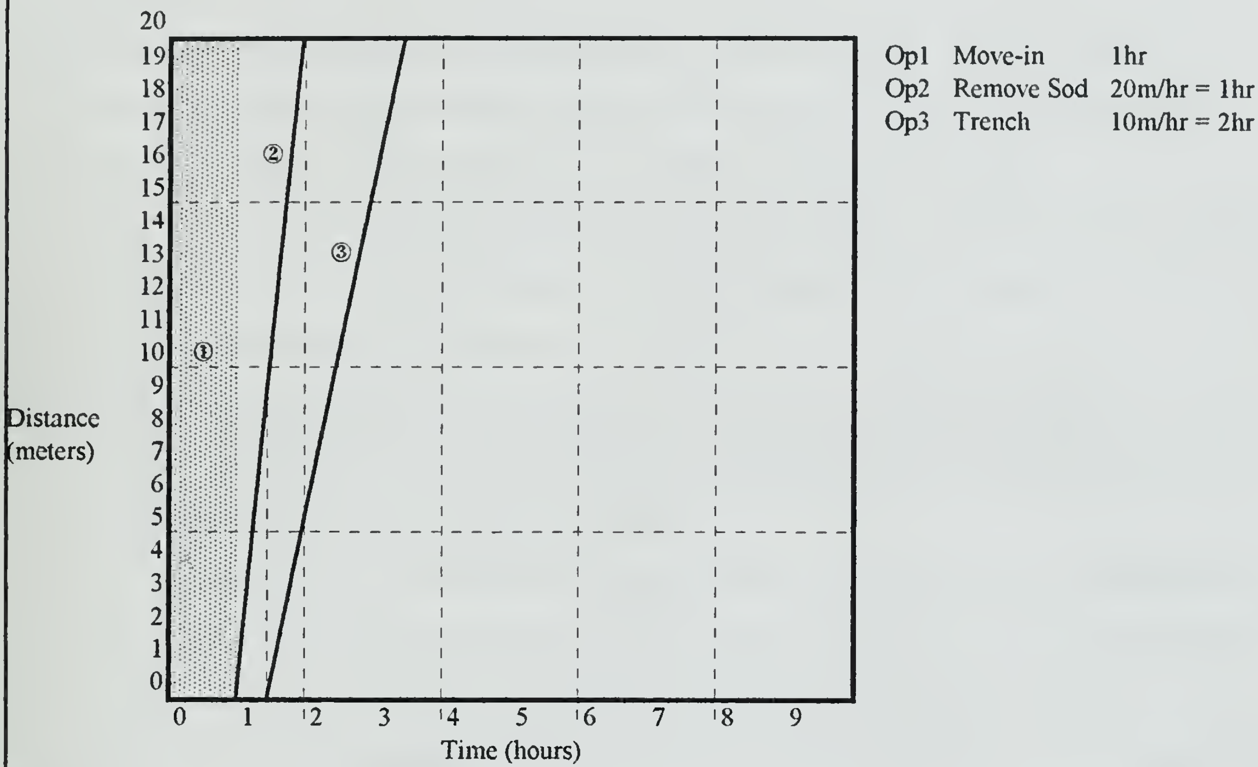


Fig. 3-4

Op 4 - Lay Pipe: As with Op 3, Op 4 has a distance- [safety-] based constraint. In this case, the slope of the operation is greater than that of its predecessor. The space between the operations will decrease with time; therefore, the critical point will be the end of the preceding operation. That is, Op 4 shall not have gotten any closer to Op 3 than the required 5 meters at the time t when Op 3 is completed. To ensure the constraint is met, follow the following procedure:

a. Drop a vertical line (vertical because the constraint is distance-related and distance is the vertical axis) from the finish point on Op 3; the length of this vertical line will be the constraining distance of 5 meters.

b. If Op 4 is begun at its earliest opportunity, then Op 4 will intersect the lower terminus of the vertical line. The planner/scheduler can determine the start and finish times of this operation (Op 4) given a point and the slope.

c. As with op 3, the vertical line was simply a tool for constructing the line representing Op 4; therefore, once the line representing Op 4 is constructed, this vertical line may be erased. (Again, the vertical line may simply be visualized; it need not actually be drawn.)

Construct a line intersecting point (t=3, d=20-5=15) with a slope of 50 m/hr. (Refer to fig 3-5, on next page.)

20-Meter Sanitary Sewer Extension

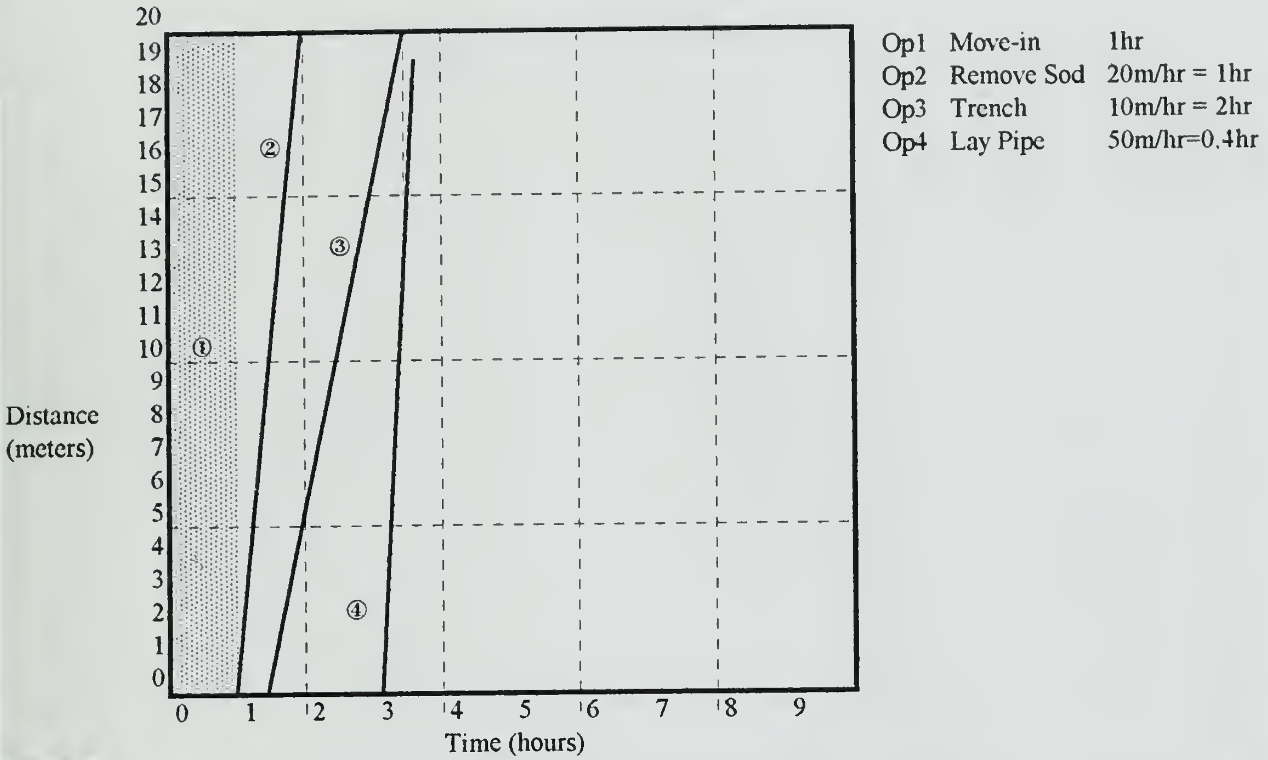


Fig. 3-5

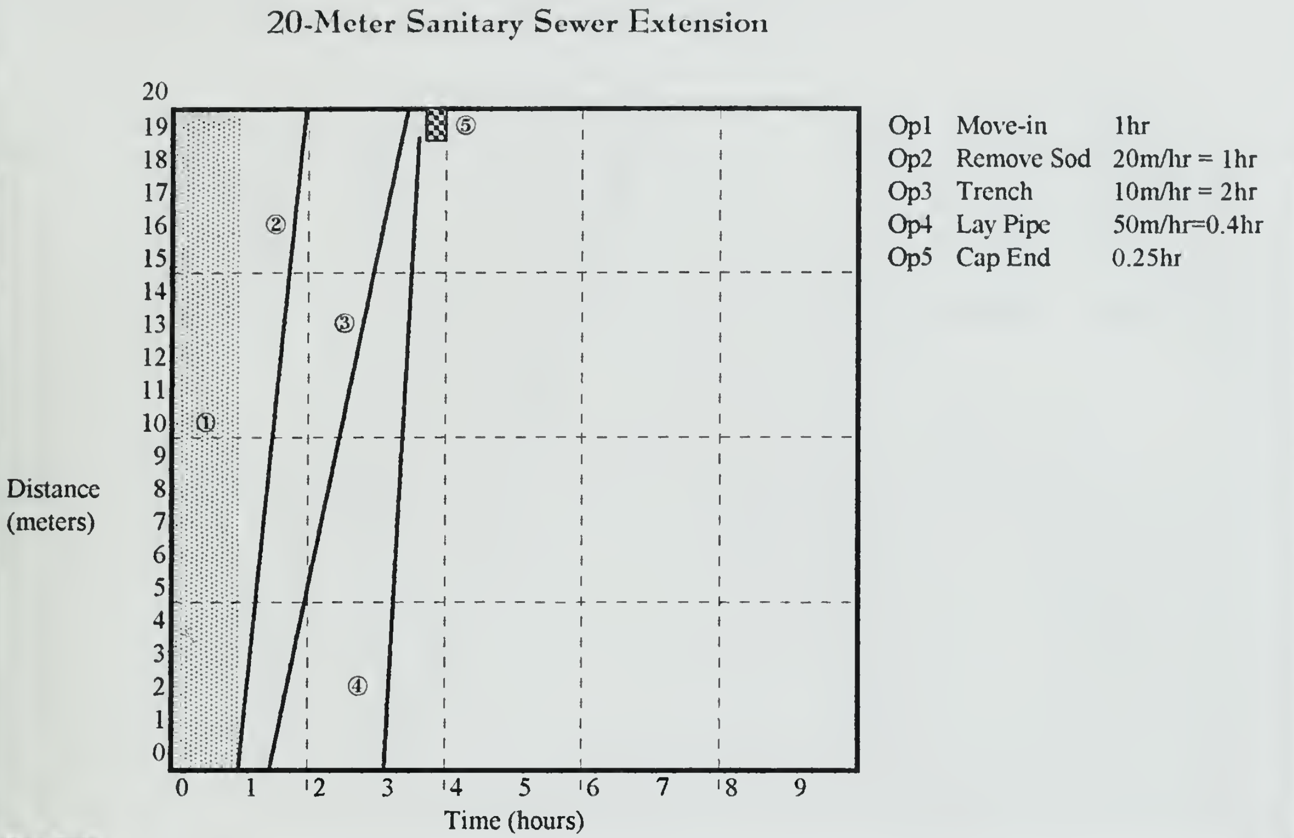


Fig. 3-6

Op 5 - Cap End of Pipeline: The planner has chosen to complete this activity after the pipe is in place. (The planner could have chosen to cap the final length of pipe before installation.) This is an activity that takes place at a single point in space over a period of time; it, therefore, will be a bar.

Construct a bar bounded by t≈3.75, t≈4, d=19 and d=20. (Refer to fig 3-6, above.)

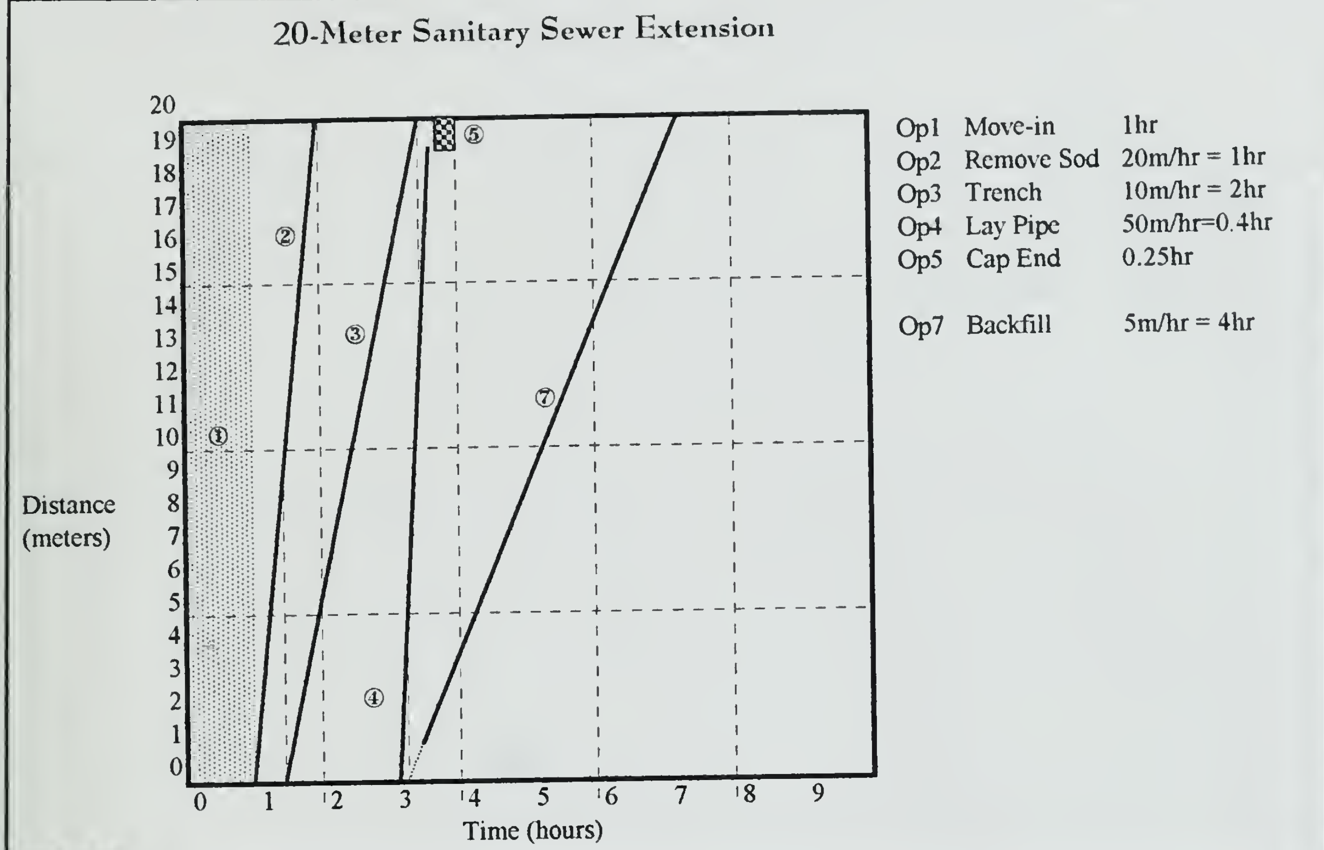


Fig. 3-7

Op 7 - Backfill & Compact Over Pipeline: This line is constructed in that same manner as Op 3. That is, Op 7 has a slope more shallow than that of its predecessor, Op 4; therefore, work from the start point of Op 7 based on the distance-related constraint of a 5-meter separation. Note, since Op 7 does starts at d=1 rather than d=0, the start point of this line must be project from the horizontal axis to 1 meter above the axis (refer to additional comments on the following page).

(Refer to fig 3-7, above.)

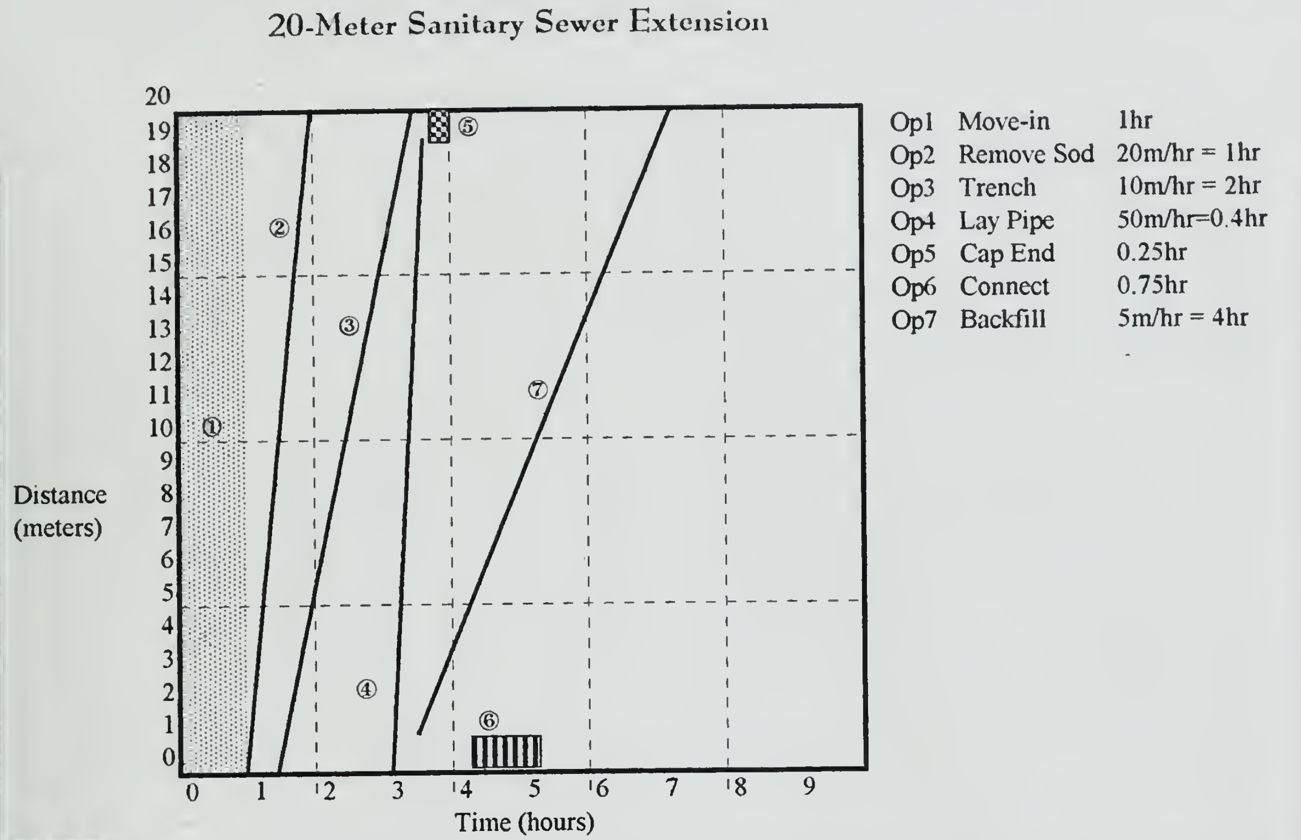


Fig. 3-8

Op 6 - Connect to Existing: The planner/scheduler has some flexibility in the timing of this activity; however, it certainly makes sense to delay this activity until the pipeline extension is in place and the terminus is capped. In the interest of time, it would be convenient to begin the backfill operation (Op 7) as soon as possible; therefore, Op 7 will commence about 1-meter from the connection point, and op 6 will include backfill/compaction over the connection. Based on this scheme, the planner/scheduler need only ensure that Op 6 can start after Op 5 is completed.

Construct a bar bounded by $t \approx 4.25$, $t \approx 5.25$, $d=0$ and $d=1$. (Refer to fig 3-8, above.)

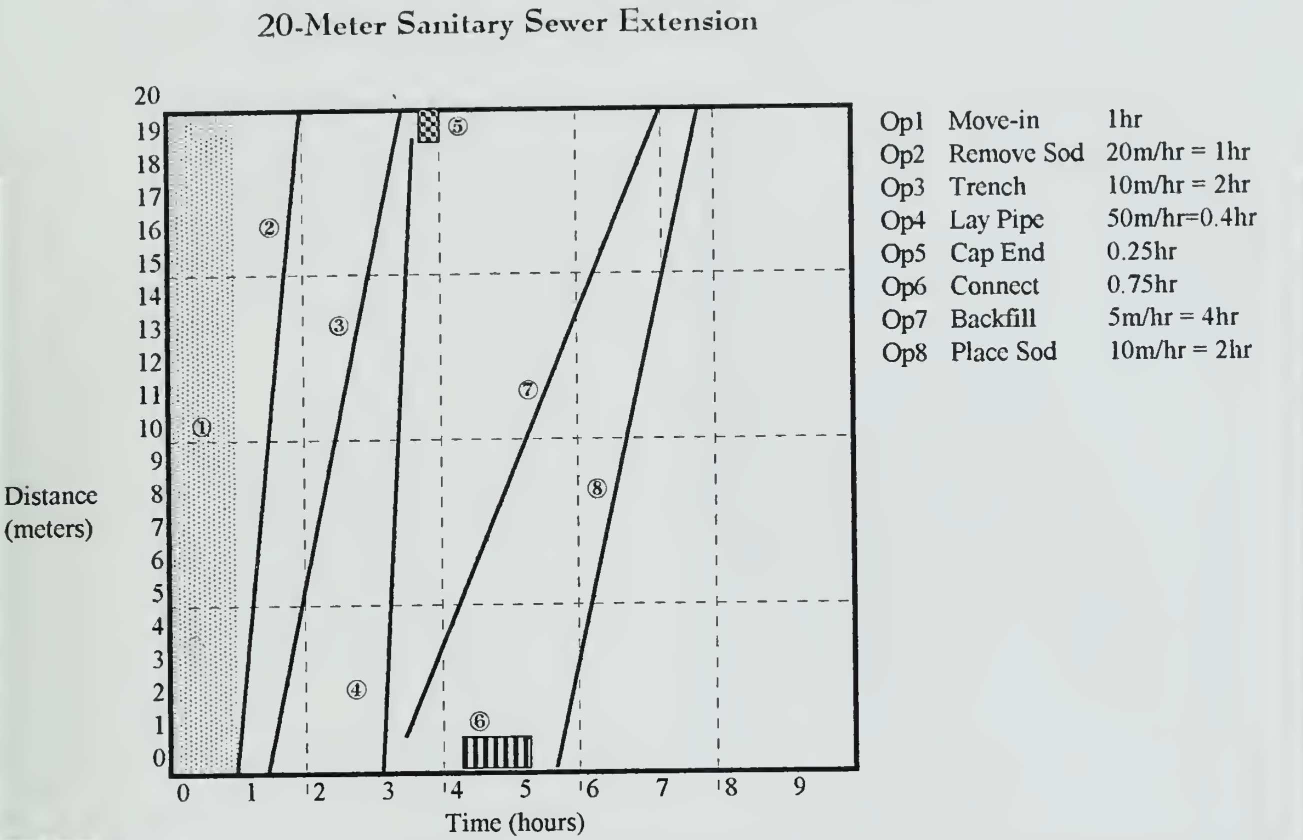


Fig. 3-9

Op 8 - Replace Sod: The primary constraint of this activity is a requirement that Op 8 and Op 7 be separated by at least 5-meters. Since the slope of Op 8 is greater than the slope of Op 7, the location of Op 8 on the schedule will be dependent on the finish time of op 7. (Refer back to Op 4 for discussion.) Dropping a 5-meter vertical line from the end of the Op 7 line gives us a point on the Op 8 line. (Note that the planner/scheduler may choose to shift the line representing op 8 to the right of this point if it is convenient to do so - say if equipment is being shared with some other work; however, the line representing Op 8 may not be shifted to the left of this point.) Given this point and the slope of the line, the planner scheduler may calculate the planned start and finish times for the Op 8.

(Refer to fig 3-9, above.)

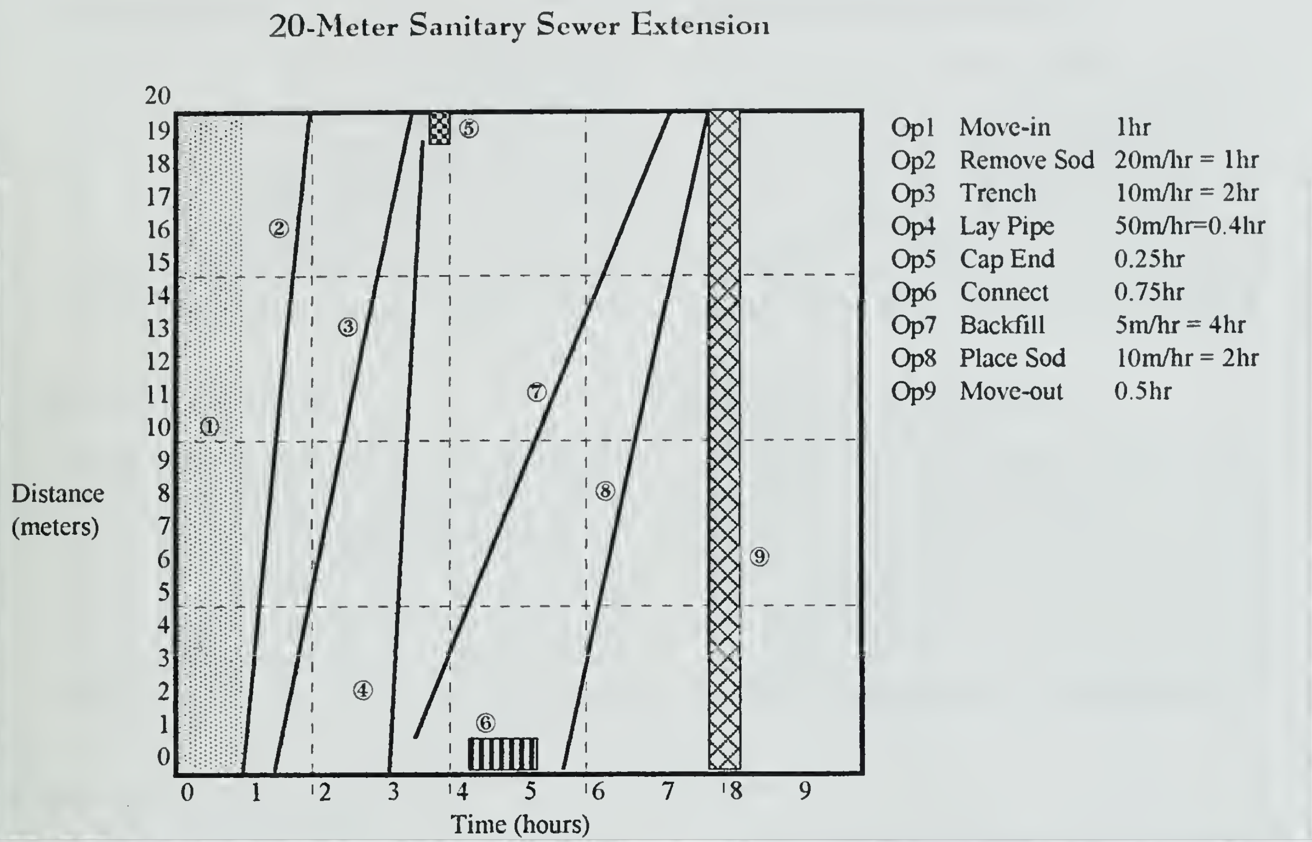


Fig. 3-10

Op 9 - Clean-up/Move-out: Finally, the last activity, like the first, is not linear.

Construct a block of width=0.5hr with the top right corner coincidental with the end of Op 8. (Refer to figure 3-10, above.)

(Note that operations Op 5 and Op 6 have some float. The two operations require a combined total time of 1 hour, are scheduled to be completed in a total elapsed time of 1.5 hours, and can be delayed for a total elapsed time of 2 hours.)

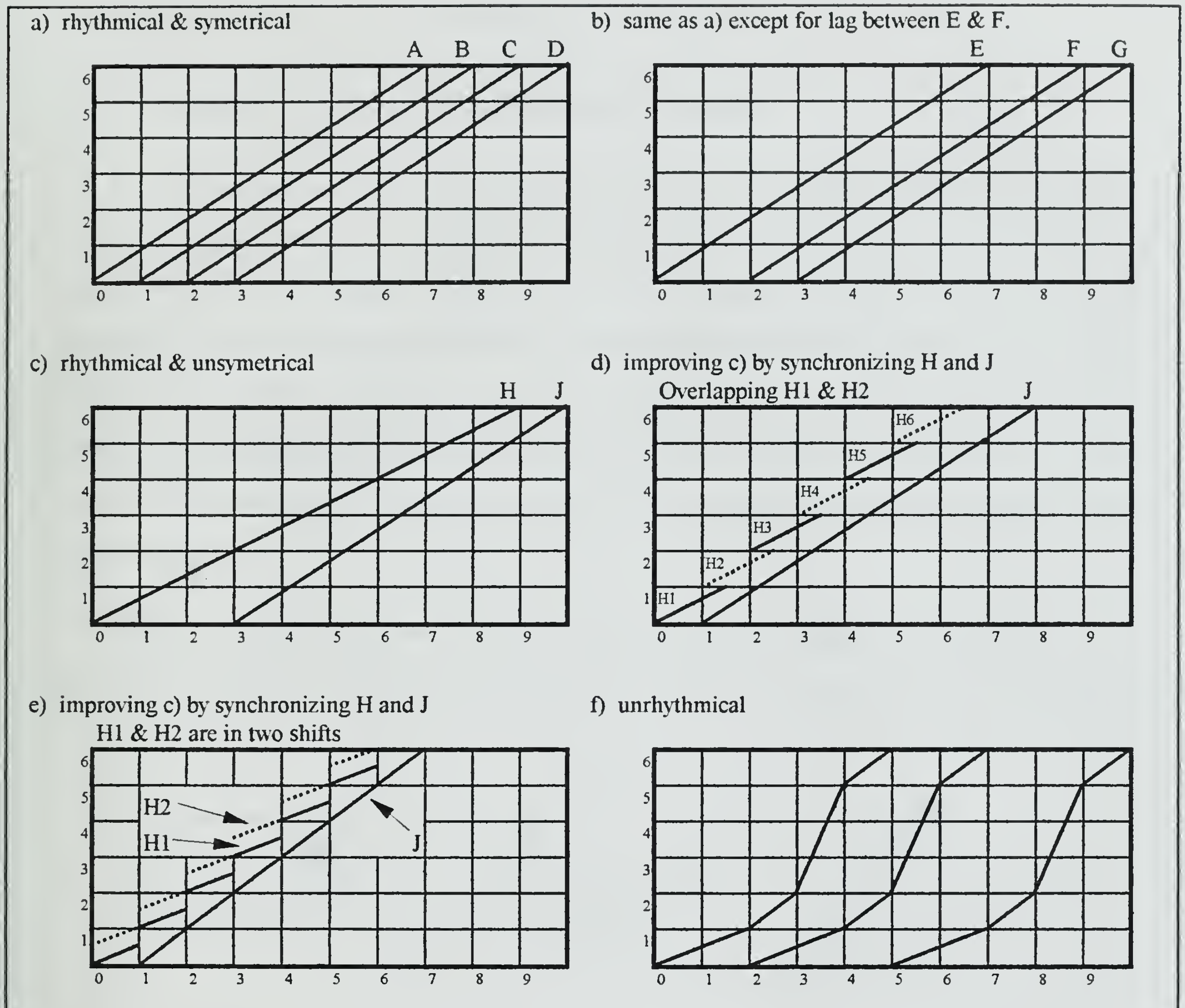


Fig. 3-11

3.4 Additional Commentary

As with other scheduling methods, the planner/scheduler has some discretion in planning the work. Production rates may vary due to such factors as available resources, crew experience and anticipated weather conditions. Likewise, the relationships between adjacent operations may be vary; this may, for example, be due to safety considerations.

The above charts (figure 2-11) provide examples of how a linear schedule may vary in order to

meet the requirements of a particular project.

3.4.1 Secondary Symbols & Supplemental Information

In addition to the basic symbols included in the linear schedule (block, bar and line), other symbols or information may be used for added detail. One must balance the amount of detail used against the size and complexity of the project. For any given project, there comes a point where added detail increases confusion rather than clarity. This point varies from project to project and also depends on the specific goals of those using the schedule. (In some cases it may be convenient to prepare multiple schedules of varying detail: minimal detail to provide the owner with a project overview; additional detail to provide the foreman with sufficient information to prepare for the upcoming week.)

Additional symbols often used in linear schedules are shown in figure 3-12, below[4,5,6].

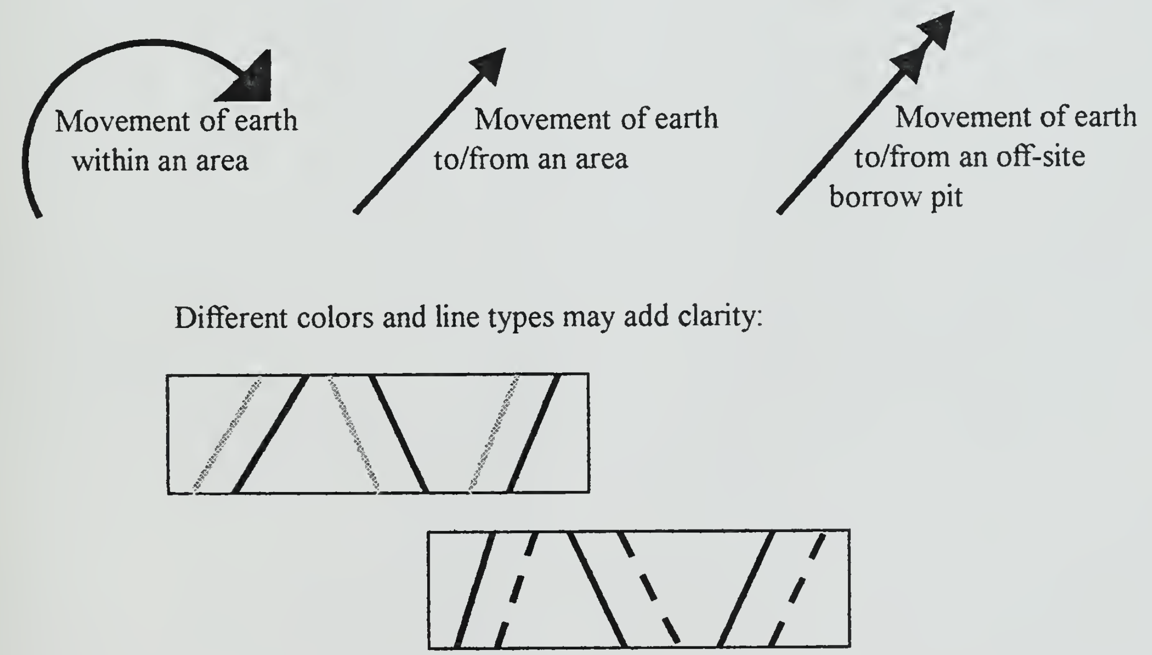


Fig. 3-12

Chapter Endnotes

1. Roads & Bridges, "LAW: The Contractor's Side," Pavin, September 1997.

2. Ibid.

3. Roads & Bridges, "LAW: The Contractor's Side," Pavin, September 1997.

4. Linear Scheduling Method, Donald G. Mueller, 1997.

5. A Multi-Project Scheduling Procedure for Transportation Projects, Rowings, Harmelink and Rahbar, April 1993.

6. Micro-Computer Based Linear Scheduling Application for Highway Construction Project Control, Rowings and Harmeling, October 1995.

Chapter 4
State DOT Survey Results

State Dept of Transportation[1]	Reports using LSM Yes	No	Reports Familiarity w/ LSM Very	Somewhat	None
Alabama		✗			✗
Arizona		✗			✗
Arkansas		✗			✗
California		✗			✗
Colorado		✗		✔	
Connecticut	✔[2]		✔✔		
Delaware		✗		✔	
Florida		✗[5]		✔	
Georgia		✗[6]		✔	
Idaho		✗			✗
Indiana		✗			✗
Iowa		✗[7]		✔	
Kansas		✗			✗
Kentucky		✗		✔	
Louisiana		✗			✗
Maryland		✗			✗
Mississippi		✗			✗
Missouri		✗			✗
Montana		✗			✗
Nebraska		✗[3]			✗
New Jersey		✗		✔	
New York		✗		✔	
Nevada		✗		✔	
North Carolina		✗			✗
North Dakota		✗			✗
Oregon		✗[3]			✗
Pennsylvania		✗[3]			✗
South Carolina		✗			✗
South Dakota		✗			✗
Texas	✔[2]		✔✔		
Utah		✗[4]			✗
Vermont		✗			✗
Virginia	At contractors' option[9]		✔✔		
Washington		✗			✗
West Virginia		✗			✗
Wisconsin	Not Required[9]			✔	

Table 4-1

See notes & commentary on next page.

Notes:

[1]Only 36 states, as listed, responded to the survey.

[2]Reports using in claim analysis.

[3]Reports using LSM; actually using Bar Charts/CPM.

[4]Reports using LSM; actually using SureTrak.

[5]Interested, but wants better software; has funded research with University of Florida.

[6]Considering trial use with some projects.

[7]Has funded research to develop specifications & software.

[8]Was used by a contractor in a recent claim.

[9]Used by several contractors.

General Commentary

Dr. Zohar Herbsman of the University of Florida sent surveys to each of the state departments of transportation. The results, as reported in Table 4-1 above, were received in late 1997 and early 1998.

As shown in table 4-1, no state DOT uses LSM as a matter of course (whereas some states, such as Florida, in fact require the use of CPM).

However, several states use LSM in their claims analysis. The data also indicates that a number of contractors, given the choice, use LSM vice CPM.

The data seems to indicate that there is definite interest in using LSM in the highway construction industry; however, there is insufficient familiarity and no apparent driving force to encourage more widespread use.

Chapter 5
Case Studies

The following case study further demonstrates the practical applicability of linear scheduling techniques, particularly with respect to road construction.

The author compares the contractors' original bar chart progress schedule to a linear progress schedule prepared by the author using data obtained from FDOT. It should be noted that it is not the intent of the author to make any qualitative statements (implied or explicit) regarding the feasibility of the contractor's planning or the ability of the contractor to follow a schedule or manage a project. The intent of the analysis contained herein is simply to compare the value of a linear progress schedule to that of a bar chart progress schedule with respect to project management.

5.1 Case Study

5.1.1 Project Description.

Lead Project No. 72015-3506
Contract Days (original): 90
Location:

FDOT Resident Office:
Jacksonville Construction

Duvall County, State Road 126, a distance of 1,139.664 meters from STA 29+84 (K.P. 1,716) to STA 41+23.664 (K.P. 3,819).

5.1.1.1 General Description of Scope:

The Contractor is required to mill the existing bituminous pavement surface to an average approximate depth of 80mm; provide a bituminous structural course; and provide a bituminous friction course.

Ancillary to the above, the Contractor is to provide sod, curb & gutter, sidewalks, temporary pavement markings, and permanent pavement markings. Prior to commencement of milling operations, it is necessary for the Contractor to coordinate with local agencies regarding the location and condition of utilities.

5.1.2 Contractor's Original Progress Schedule. The Contractor initially provided a bar chart schedule (Figure 5-1) showing completion after 90 calendar days, in accordance with the 90-calendar-day contractual requirement. The Contractor's schedule included the following tasks:

Table 5-1

Act ID	Description	Orig Dur	Early Start	Early Finish	CP
10	Begin Project	1	11/12/97	11/12/97	✗
20	Maintenance of Traffic	52	11/12/97	02/05/98	
30	Clearing & Grubbing	4	11/13/97	11/18/97	✗
40	Milling Existing Asphaltic Pavement	6	12/29/97	12/16/97	✗
50	Asphaltic Concrete	10	12/10/97	12/23/97	✗
60	Asphaltic Concrete Friction Course	6	01/22/98	01/29/98	✗
70	Adjust Manhole & Grate Replace	6	11/19/97	11/26/97	✗
90	Pipe Cleaning, Sealing & Liner	6	12/01/97	12/08/97	✗
100	Curb & Gutter	4	01/13/98	01/16/98	✗
110	Sidewalk Concrete	6	01/05/98	01/12/98	✗
120	Temp Markings & Striping	3	01/05/98	01/07/98	✗
130	Install Signal Loop Wire	5	01/08/98	01/14/98	
140	Permanent Markings & Striping	4	01/30/98	02/04/98	✗
150	Sodding	3	01/19/98	01/21/98	
160	Job Clean-up	3	02/05/98	02/09/98	✗
170	Bell South (locate utilities)	10	11/19/97	12/04/97	
180	City of Jax (lower water valves)	5	11/19/97	11/25/97	
190	City of JAX (raise water valves)	10	01/08/98	01/21/98	✗
200	JEA (locate & protect utilities)	1	11/19/97	11/19/97	

The Contractor's bar chart (Fig 5-1) was generated using Primavera Project Planner software. It indicates the planned start and completion dates for each activity. It provides a general indication of relative order, using lines and arrows between activity bars. Total float is also indicated, giving an indication of the critical path.

5.1.2.1 General Analysis of Contractor's Bar Chart Schedule.

Using this type of progress schedule for linear operations often results in various ambiguities; these ambiguities have the potential effect of making it difficult for the contractor to effectively manage the project. This is particularly troublesome if the progress schedule is not prepared by the job-site superintendent or other on-site management personnel, or if there is a change in superintendent or foreman. For example, a careful review of figure 5-1 reveals the following:

It is clear, for example, from the original bar chart progress schedule that milling and structural course paving will be executed concurrently, with milling starting in advance of the paving operations; however, it is not clear *how* these concurrent operations will be executed in order to meet schedule requirements. i.e. will the contractor mill one lane at a time, with the paving operation immediately following the milling operation? Perhaps the contractor planned to close all eastbound lanes, diverting all traffic to the westbound lanes during milling and paving; then moving all traffic to the eastbound lanes while milling and paving the westbound lanes. Additionally, if the contractor's original estimation of the production rate for milling was in error by a significant amount, this may not become apparent until several days into the operation. What's more, it is not apparent from a review of the schedule how such a delay would affect the

paving operation.

Likewise, it is not apparent from a review of the bar chart schedule how long it would take to recognize delays in paving or how these delays would affect the remainder of the scheduled operations.

The bar chart does not reveal, for example, how the milling operation will proceed. Will the Contractor close a single lane of traffic for the entire length of the project, remove the existing asphalt, close the next lane, and so on?

5.1.3 Linear Progress Schedule.

5.1.3.1 Relative Analysis of Linear Progress Schedule (with respect to 5.1.2.1).

Using a linear scheduling methodology, a manager can determine from the schedule *how* the planner actually intended the work to proceed. This is true even if the manager in question has little experience with this type of construction. For example, the plan may be to mill the right, outside shoulder from the western limit of the project to the eastern limit; then mill the left outside shoulder from the eastern limit to the western limit; then mill the right outside lane from west to east, and so on. If so, this will be readily apparent from a cursory review of the linear progress schedule. Even an inexperienced manager can determine how actual progress compares to planned progress from a cursory review of a linear schedule.

Since the linear schedule indicates exactly when and where on the project site operations are to be performed, the linear schedule becomes immediately useful, with little or no other input, in determining *early on* in the progress of an operation whether the operation is on schedule. This enables managers to more

readily analyze construction progress in order to develop and implement corrective or remedial action with respect to delays. What's more, the linear schedule is equally useful in analyzing claim situations. Because the linear progress schedule relates time and space to progress, an updated linear schedule facilitates the determination of precisely when and where delays occurred. This makes it much more apparent which party is liable for delay costs.

5.1.3.2 Development of the Linear Progress Schedule.

5.1.3.2.1 Choosing Axes.

As indicated in Chapter 2 of this report, the first step in developing the linear schedule is to choose the axes for the graphical representation of the progress schedule. In this case, the author chose to represent time on the horizontal axis and to represent distance on the vertical axis.

Having time on the horizontal axes better facilitates ready comparison between the linear progress schedule and the bar chart progress schedule. Also, in the opinion of the author, it is easier to read a graphic schedule when the longer axis is on the horizontal. In this case, the time axis was expected to be the longer axis.

5.3.1.2.2 Choosing Activities/Operations for Inclusion in the Linear Schedule.

In the Contractor's original bar chart progress schedule, a number of activities are shown which provide no added value to the progress schedule *as a scheduling tool*. In all likelihood, these activities are included simply for purposes of invoicing. For example, "Maintenance of Traffic" is included as an activity on the original progress schedule. From the schedule, it is obvious that the Contractor

Operations

1. Move-in/Start-up	5. Temporary Striping	9. Sodding
2. Milling Pavement	6. Install Signal Loop Wire	10. Place Asphalt (Friciton Course)
3. Place Asphalt (structural course)	7. JAX (water valves)	11. Permanent Striping
4. Sidewalk Concrete	8. Curb & Gutter	12. Clean-up/Move-out

Table 5-2

To improve clarity, operations listed in Table 5-2 will be subdivided, when appropriate, on the graphical representation as follows :

a. Right Outside Shoulder (ROS)	e. Left Inside Lane (LIL)
b. Right Outside Lane (ROL)	f. Left Outside Lane (LOL)
c. Right Inside Lane (RIL)	g. Left Outside Shoulder (LOS)
d. Center Turn Lane (CTL)	

Table 5-3

5.3.1.2.3 Estimating Production Rates.

The author had the luxury of preparing a "planned" progress schedule after work on the project had commenced. For this reason, an attempt was made to determine production rates from available FDOT daily. Because of the format and level of detail currently required by FDOT in the daily reports, it was not possible to determine or estimate production rates for all operations using the daily reports. It was possible, however, to estimate reasonable production rates for Milling (Contractor Activity ID#40 @ 450 $^{m}/_{hr}$) and Asphalt Paving (Contractor Activity ID#50 @ 430 $^{m}/_{hr}$). Tables 5-5 and 5-6 provide the results.

For the remainder of the operations, the net duration (in work days), as shown on the Contractor's bar chart and the project length (from STA 29+84 to STA

41+23), were used to estimate production rates. Table 5-4 lists operations and production rates used in developing the graphic representation of the linear schedule, Figure 5-2.

5.3.1.2.4 Plotting the Graphical Representation.

Once the orientation of the axes and the operations to be included have been determined, and once the production rates for those operations have been estimated, the planner may prepare the graphical plot. This may be done by hand on graph paper, or using a PC and software (e.g. the author used Microsoft Excel.

Plotting the schedule proceeded as described in Chapter 3.

5.1.4 Further Analysis.

Note that the Linear Schedule, Figure 5-2, gives, relative to the bar chart progress schedule, a better indication of methodology and crew progress, as well as planned start and finishes dates. For example, the schedule indicates that milling is planned to commence with the right, outside shoulder at Station 29+84, followed by placing the structural course and temporary striping; further, there is a 1-hour delay between the start of the milling operation and the subsequent paving operation. For each operation, upon completion of the right, outside shoulder, the crew will move to the left, outside shoulder, progressing in the opposite direction.

With the bar chart schedule, the superintendent can only determine with any certainty whether an activity was started or completed on the date planned. Any further analysis of the progress of an activity relies heavily on other data, including the experience or "gut feelings" of project personnel.

Using the linear schedule, the superintendent can not only see that the initial milling operations should be completed in one week, he/she can also predict that the milling crew should complete milling of the right, outside shoulder approximately 2½ hours after work commences on day 29. Further, the superintendent may plan on opening the shoulder to traffic approximately six hours after work commences on day 29. If the work actually progresses at a slower or faster rate, the superintendent should be able to determine this relatively quickly, determine what remedial action, if any, is warranted, and take corrective action promptly. The ability to make such decisions at or near the beginning of a phase of operations enables to Contractor to better minimize or eliminate the detrimental effects of variances in the progress schedule.

Likewise, the Linear Schedule provides a greater degree of comfort for the Owner for the same reasons: it is readily apparent that there is a logical plan for prosecution of the work; it is readily apparent whether the work is on schedule; and it is more readily apparent what effects a variance in one operation will have on other operations and on overall project completion.

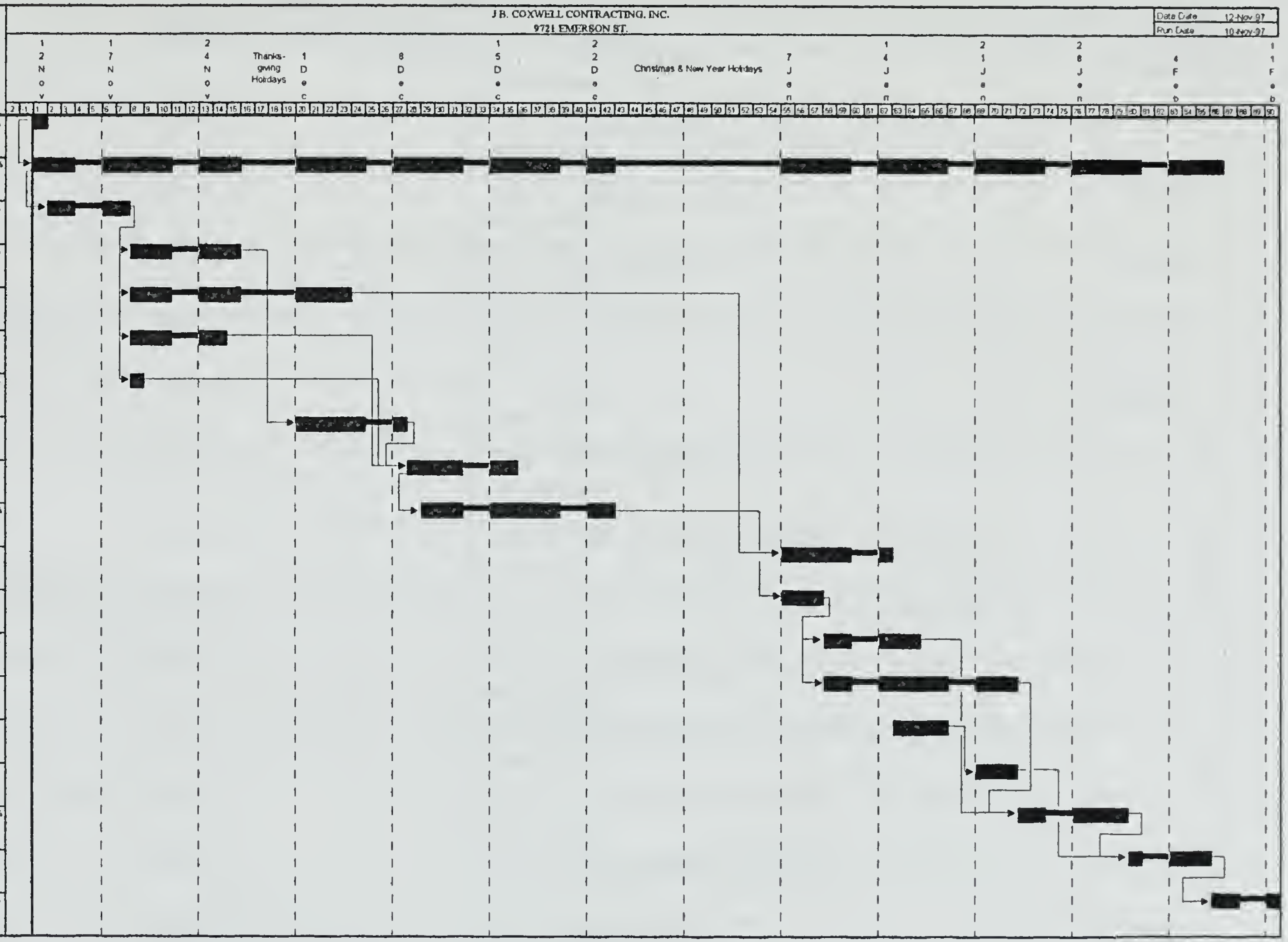
Finally, because this graphical, time-space format provides a more clear snap-shot of the project's progress, it's use helps to reduce the potential for claim situations to arise. Since the relationship between planned progress and actual progress is more clear, the parties to a contract should be more able to reach a consensus as to the root cause(s) of delays.

72015-3506

Figure 5-1

PROGRESS SCHEDULE

Act ID	Description	Dur	Early Start	Early Finish	Total Float	% of Bid
10	BEGIN PROJECT $15,546.83	1	12-Nov-97	12-Nov-97	0	3.92%
20	M O T $39,900.09	52	12-Nov-97	5-Feb-98	2d	10.07%
30	CLEARING & GRUBBING $36,471.72	4	13-Nov-97	18-Nov-97	0	9.20%
70	ADJUST MANHOLE & GRATE REPLACE $5,983.90	6	19-Nov-97	26-Nov-97	0	1.51%
170	BELLSOUTH (LOCATE EXISTING UTILITIES) $0.00	10	19-Nov-97	4-Dec-97	19d	0.00%
180	CITY OF JAX (ADJUST WATER VALVE -LOWER) $0.00	5	19-Nov-97	25-Nov-97	7d	0.00%
200	JEA (LOCATE & PROTECT UTILITIES $0.00	1	19-Nov-97	19-Nov-97	11d	0.00%
90	PIPE CLEANING, SEALING & LINING $26,065.72	6	1-Dec-97	8-Dec-97	0	6.58%
40	MILLING ASPHALT PAVEMENT $26,132.75	6	9-Dec-97	16-Dec-97	0	6.59%
50	ASPHALTIC CONCRETE $150,601.37	10	10-Dec-97	23-Dec-97	0	38.00%
110	SIDEWALK CONCRETE $10,491.39	6	5-Jan-98	12-Jan-98	6d	2.65%
120	TEMP MARKINGS & STRIPING $8,060.17	3	5-Jan-98	7-Jan-98	0	2.04%
130	INSTALL SIGN LOOP WIRE $3,523.80	5	8-Jan-98	14-Jan-98	5d	0.89%
190	CITY OF JAX (ADJUST WATER VALVE - RAISE) $0.00	10	8-Jan-98	21-Jan-98	0	0.00%
100	CURB & GUTTER $3,694.75	4	13-Jan-98	16-Jan-98	6d	0.93%
150	SODDING $3,829.34	3	19-Jan-98	21-Jan-98	6d	0.97%
60	ASPHALT CONCRETE FRICTION COURSE $58,377.55	6	22-Jan-98	29-Jan-98	0	14.73%
140	PERMANENT MARKS & STRIPING $7,677.91	4	30-Jan-98	4-Feb-98	0	1.94%
160	JOB CLEAN-UP $0.00	3	5-Feb-98	9-Feb-98	0	0.00%



Contractor's original schedule was prepared using Primvera software; it was reproduced by the author using Microsoft Excel for inclusion in this report.

Production Rates

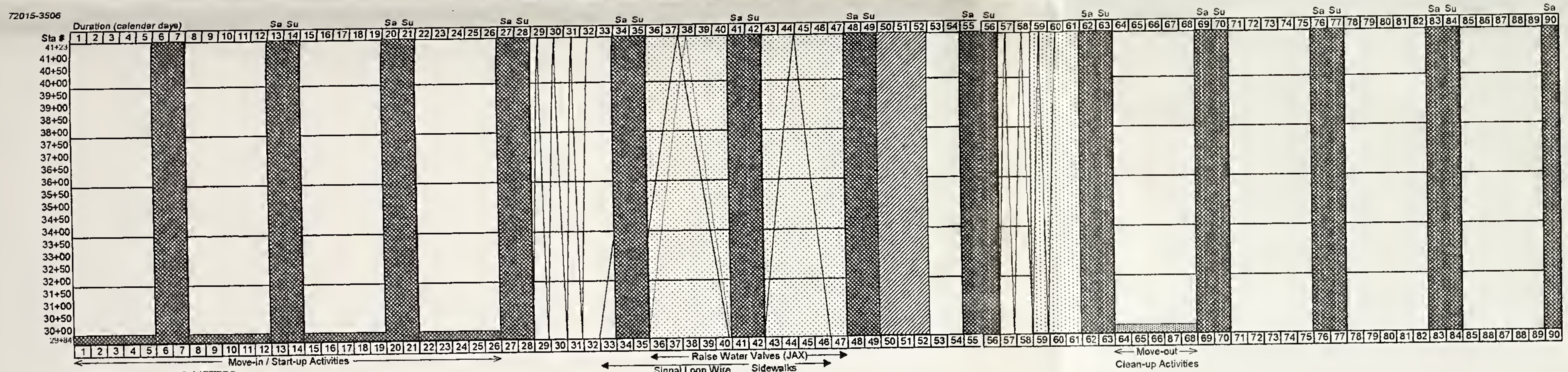
Table 5-4

Op #	Operation	Production Rate Hourly	Production Rate Daily	Total Time	Op #	Operation	Production Rate Hourly	Production Rate Daily	Total Time
1	Move-in / Start-up Constraints / Notes: Includes move-in, clear & grub, and locate/adjust/protect utilities			4 weeks	4	Sidewalk Concrete Constraints / Notes:			6 days
2a	Milling Pavement (ROS) Constraints / Notes:	420 m/hr			5	Temporary Striping Constraints / Notes:	470 m/hr		
2b	Milling Pavement (ROL) Constraints / Notes:	420 m/hr			6	Install Signal Loop Wire Constraints / Notes:			5 days
2c	Milling Pavement (RIL) Constraints / Notes:	420 m/hr			7	JAX (water valves) Constraints / Notes:			10 days
2d	Milling Pavement (CtrTurnLane) Constraints / Notes:	420 m/hr			8	Curb & Gutter Constraints / Notes:			4 days
2e	Milling Pavement (LIL) Constraints / Notes:	420 m/hr			9	Sodding Constraints / Notes:			3 days
2f	Milling Pavement (LOL) Constraints / Notes:	420 m/hr			10a	Place Asphalt (Friction Course / ROS) Constraints / Notes:	450 m/hr		
2g	Milling Pavement (LOS) Constraints / Notes:	420 m/hr			10b	Placing Asphalt (Friction Course / ROL) Constraints / Notes:	450 m/hr		
3a	Placing Asphalt (Structural / ROS) Constraints / Notes:	450 m/hr			10c	Placing Asphalt (Friction Course / RIL) Constraints / Notes:	450 m/hr		
3b	Placing Asphalt (Structural / ROL) Constraints / Notes:	450 m/hr			10d	Placing Asphalt (Friction / Ctr Turn Lane) Constraints / Notes:	450 m/hr		
3c	Placing Asphalt (Structural / RIL) Constraints / Notes:	450 m/hr			10e	Placing Asphalt (Frictoin Course / LIL) Constraints / Notes:	450 m/hr		
3d	Placing Asphalt (Structural / Ctr Turn Lane) Constraints / Notes:	450 m/hr			10f	Placing Asphalt (Friction Course / LOL) Constraints / Notes:	450 m/hr		
3e	Placing Asphalt (Structural / LIL) Constraints / Notes:	450 m/hr			10g	Placing Asphalt (Friciton Course / LOS) Constraints / Notes:	450 m/hr		
3f	Placing Asphalt (Structural / LOL) Constraints / Notes:	450 m/hr			11	Permanent Striping Constraints / Notes:			3 days
3g	Placing Asphalt (Structural / LOS) Constraints / Notes:	450 m/hr			12	Clean-up / Move-out Constraints / Notes:			1 week

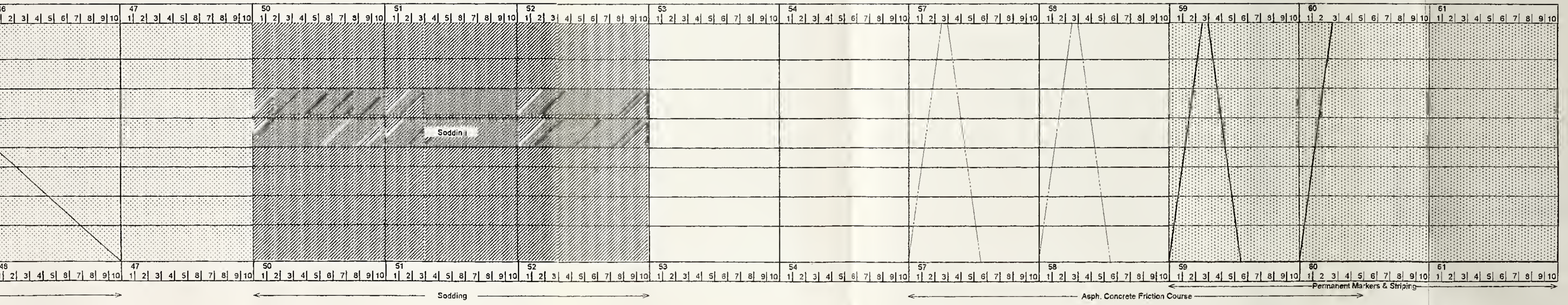
Milling Paving
(Actual Production)

Date	Milling	Stations Start	Stations Finish	Distance	Time Start	Time Finish	Total	Produciton Rate
01-Dec-97	R1 rt rdwy @ 40mm	2984	4183	1,199 m				
	Lt rdwy parking lane @ 40mm	4183	2984	1,199 m				
	L2 lt rdwy outside lane @ 40mm	4183	2984	1,199 m				
	R1 rt rdwy @ 40mm	2984	4183	1,199 m				
				4,796 m	6:00 PM	5:00 AM	11.0 hrs	436 m/hr
01-Dec-97	R2 @ 40mm	2984	4183	1,199 m				
	Parking lane, rt rdwy @ 40mm	3950	4150	200 m				
	L2 @ 40mm	4183	2984	1,199 m				
	R1 rt rdwy @ 40mm	3984	3905	79 m				
				2,677 m	6:00 PM	12:30 AM	6.5 hrs	412 m/hr
04-Dec-97	R1 @ 40mm	2984	4183	1,199 m				
	R2 @ 40mm	2984	4183	1,199 m				
	L2 @ 40mm	4183	2984	1,199 m				
	Parking lane, lt rdwy @ 40mm	4183	2984	1,199 m				
				4,796 m	6:30 PM	6:00a	11.5 hrs	417 m/hr
	Average Production Rate			12,269			29.0 hrs	423 m/hr
Table 5-5							Say	420 m/hr

Date	Place Asphalt	Stations Start	Stations Finish	Distance	Time Start	Time Finish	Total	Produciton Rate
04-Dec-97	R1 @ 40mm type S asphalt	2984	4183	1,199 m				
	R2 @ 40mm type S asphalt	2984	4183	1,199 m				
	L2 @ 40mm type S asphalt	4183	2984	1,199 m				
	Parking, lt rdwy @ 40mm type S asphalt	4183	2984	1,199 m				
				4,796 m	6:30 PM	6:00a	11.5 hrs	417 m/hr
07-Dec-97	Place 20mm type S asphalt center ln L1	2984	4183	1,199 m	11:00 AM	3:00 PM	4.0 hrs	300 m/hr
06-Dec-98	Place 20mm type S asphalt L2	2984	4183	1,199 m				
	Place 20mm type S asphalt R1	2984	4183	1,199 m				
	Place 20mm type S asphalt R2	2984	4183	1,199 m				
				3,597 m	10:00 AM	6:00 PM	8.0 hrs	450 m/hr
06-Dec-98	Place 20mm type S asphalt lt parking ln	2984	4183	1,199 m				
	Place 20mm type S asphalt rt parking ln	2984	4183	1,199 m				
	Place 20mm type S asphalt lt ROW	2984	4183	1,199 m				
	Place 20mm type S asphalt rt ROW	2984	4183	1,199 m				
				4,796 m	10:00 AM	6:00 PM	8.0 hrs	600 m/hr
	Average Production Rate			14,388			31.5 hrs	457 m/hr
Table 5-6							Say	450 m/hr



TOTAL LENGTH = 1,140 METERS


47
50
51
52
53
54
57
58
59
60
61
Sodding
Sodding
Asph. Concrete Friction Course
Permanent Markers & Striping

Chapter 6
Micro-Computer Based Linear Scheduling Applications

In 1991, Dr. Mike Vorster and others at Virginia Tech had developed a computer interface between CPM and linear scheduling. Essentially, the CPM schedule provided the activity dates, and then the linear schedule software converted the CPM data into a linear schedule. Apparently, the software had limited usefulness as developed.[1]

In 1995, J. E. Rowings and D. J. Harmelink developed a micro-computer based linear scheduling model[2]. Also in 1995, Michael Berns of the US Navy Civil Engineer Corps developed a computer based model[3].

The only commercial LSM software known to the author is a program called XPosition by TransCon Consulting Ltd.[4]

Of the computer models listed above, the author was only able to review the Berns model and the commercial XPosition. While XPosition seemed initially promising, it proved to be less than viable for use by the Florida (or other) Department of Transportation. The program does not allow for the manipulation of the scale. When the author attempted to use this program with Case Study #1, it merely generated illegible 8½"x11" sheet.

The Berns model allows only linear operations (no blocks or bars) and does not allow the user to establish constraints on the relationships between operations.

At present, there does not appear to be a commercially viable software package for linear scheduling. When contacted by Dr. Zohar Herbsman of the University of Florida about developing or improving software for commercial distribution, several software developers commented that they would only be interested in the effort if funding for the effort were provided. It is noteworthy that the Iowa Department of Transportation indicated, as reported in Chapter 4, that they have funded further research in the development of a viable software model.

It appears that, while there is limited use of LSM in the U.S. highway construction industry, more widespread use is hampered, in part, by the lack of suitable software. Its use is also hampered by a general lack of familiarity with LSM by those outside academic circles. However, it stands to reason that, if a viable commercial product were produced, promotion of the product by the software company would serve to increase familiarity.

Chapter Endnotes

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2. J.E. Rowings & D.J. Harmelink, "Micro-Computer Based Linear Scheduling Application for Highway Construction Project Control," Iowa Department of Transportation & Iowa Highway Research Board, October 1995

3. Michael Berns, "Developing a Computerized Line of Balance Scheduling Program for Use on Navy and General Industry Construction Projects," University of Florida, 1995

4. Cordell Pavin, "Software Aids Linear Scheduling," Roads & Bridges, September 1997

Chapter 7
Conclusions & Recommendations

7.1 Conclusions

By relating the position of crews working on specific operations or activities to a specific location at a specific time, LSM allows managers to more readily identify schedule variances and act accordingly. This, in turn, allows managers to implement better cost- and production-control measures during production. Prior to and during production, owner and contractor personnel are better able to identify and evaluate production methods and procedures, providing for a better understanding of the intended construction processes between both parties; this in turn leads to less claim situations, and allows for quicker resolution when claim situations do arise.

In the opinion of the author, the Linear Scheduling Model advocated by researches at the University of Florida, the University of Iowa, and Virginia Tech and described in this report provides a superior means of planning and monitoring construction projects that are linear in nature. Adoption of this technique, by the highway construction industry in particular, would benefit both contractors and owners. The benefit comes in the form of increased efficiency which yields better quality and/or reduced cost.

7.2 Recommendations

In light of the superiority of the LSM method over CPM for applicable projects, the following recommendations are provided:

1- As an interim measure designed to increase the familiarity with LSM, DOT's should choose pilot projects for which LSM is specified as the required scheduling method. Selected projects should be of relatively low complexity, such as milling and resurfacing projects; this will allow both state and contractor personnel to become more familiar with the technique and better enable them readily enumerate its benefits. Such projects should be dispersed throughout the state DOT's districts. Contractor, as well as DOT, personnel involved in pilot projects should then provide feedback to a focal point within the DOT so that standard contract specifications may be refined.

2- In the long term, state DOT's should refine standard contract specifications to allow the contractor (or the contractor and DOT jointly) to determine the specific scheduling method that will best serve the parties to a particular construction project while ensuring that, whatever method is chosen, the interest of the state and its citizens are best served.

3- Commercially viable software which integrates LSM with resource- and cost-management must be developed if LSM is to receive widespread acceptance. By adopting LSM when appropriate (via recommendations #1 & #2), contractors and DOTs will create an environment in which it becomes economically feasible for software companies to expend the resources to develop (or improve) LSM software. In this instance, software firms *will* not only develop LSM software, they will develop integrated project management software based on LSM, as has already been done with CPM/bar chart software. (Software producers should work with DOT's so contractor's are not required to purchase software until it has been proven to be viable; so-called "beta" versions should be provided at no cost to the contractors.)

If commercially viable software is developed for and used by the highway construction industry, it seems reasonable that other practitioners within the construction industry will adopt LSM as well.

Chapter 8
References

8.1 References

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3. J.E. Rowings & D.J. Harmelink, Micro-Computer Based Linear Scheduling Applications for Highway Construction Project Control, Iowa Department of Transportation and Iowa Highway Research Board, October 1995
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19. Cordell Pavin, Roads & Bridges, "LAW: The Contractor's Side, September 1997